Poster 45.03, 199th Meeting of the American Astronomical Society 6–10 January 2002, Washington, DC. email: lawson@huey.jpl.nasa.gov Reprints: http://huey.jpl.nasa.gov/∼lawson/aas199.4503.pdf

Cryogenic Optics for Long-Baseline Interferometry in the Far-Infrared

P.R. Lawson, M.R. Swain, P.J. Dumont, J.D. Moore and R.F. Smythe
Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA

1 Introduction

Direct-detection interferometry in space at far-infrared wavelengths will ultimately allow high angular resolution studies of galaxy and star formation and overcome the confusion due to the extra-galactic background, opening up an entirely new domain of astrophysical research (cf. Rieke *et al.* 1999). In support of these science goals, we are now at JPL developing new technologies needed to make long-baseline far-infrared interferometry possible. The design of a direct-detection interferometer for the far-IR is extremely challenging. For it to be background-limited in space in the region of 40-400 microns, its optics and servo-mechanisms must operate at near liquid helium temperatures. Our current efforts are focused on the commissioning of a precision cryogenic delay line and integrated optics beam combiner. The preliminary tests of our prototype delay line, at a temperature of 120 K, have shown the design to be fundamentally sound. We are in the process of implementing the servo control system for the delay line and have completed the fabrication and assembly of a novel cryogenic mechanical amplifier for phase-measurement interferometry. The current status and ongoing development of our program are described.

2 Overview of the Cryogenic Delay Line

Our objective has been to design a precision delay line that does not use axles, is capable of accepting 10 cm optical beams, and which provides 50 cm of optical delay while operating in hard vacuum at temperatures as low as 4 Kelvin. We choose a design wavelength of 100 μm and adopted a cat's eye optical design to facilitate path compensation with a high-speed servo. Our requirement that the fringe visibility loss be less than 1.0% is achieved if the straightness of travel is 250 μm over the full stroke and the piston jitter is less than 1.2 μm rms at a wavelength of 100 μm. As a goal we would like to demonstrate the operation of a cryogenic delay line with pathlength stability at the 5–10 nm, in support of the Terrestrial Planet Finder program.

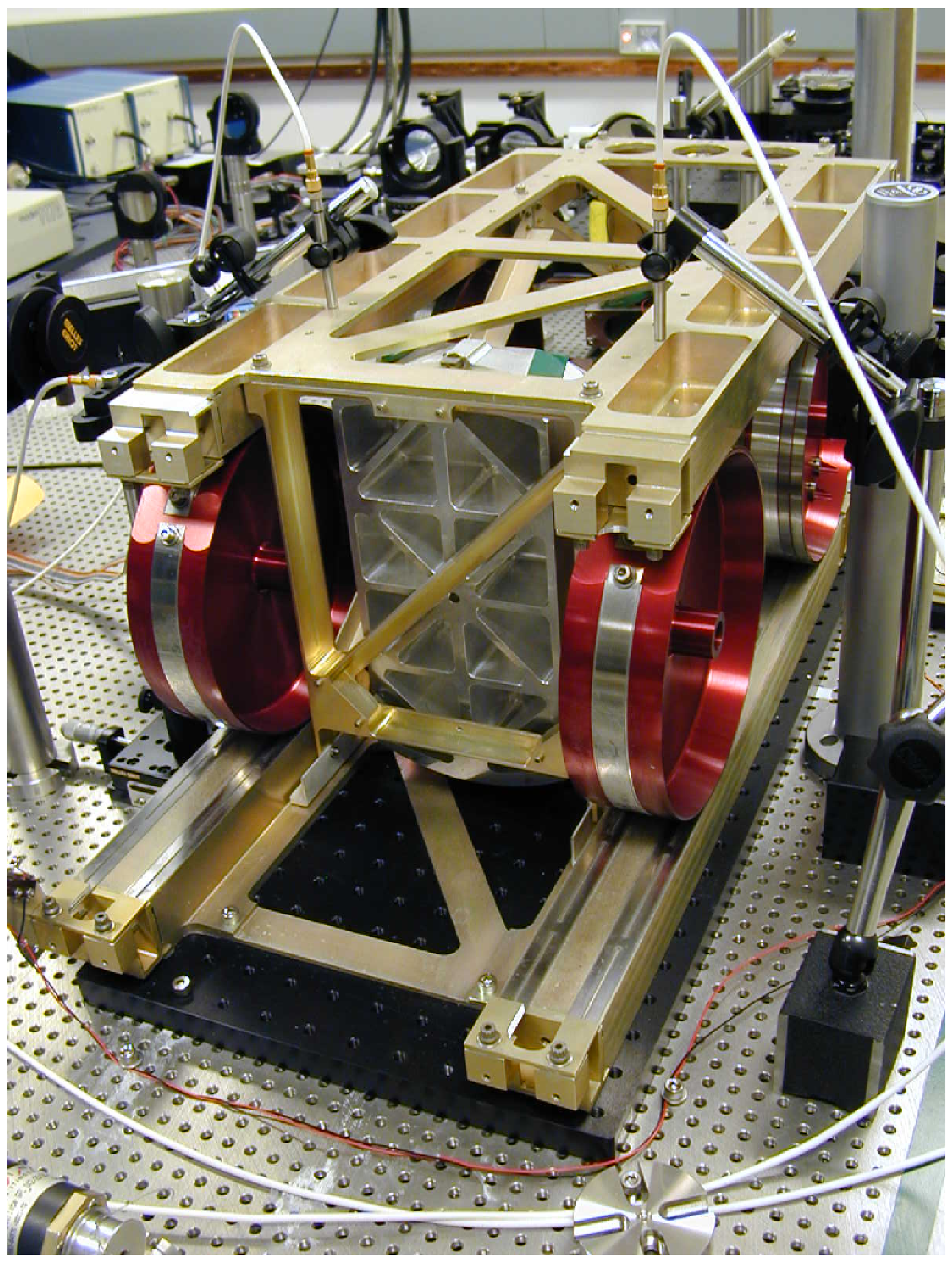

Figure 1: Cryogenic delay line with wheels constrained by straps. The upper platform supports the optics and rolls along the top of the wheels. The back of the lightweighted primary mirror is also visible.

Our initial studies focused on a "double porch swing" design using flexure pivots and developed by Donald E. Jennings at the Goddard Space Flight Center. The limited angular travel of flexure pivots motivated us to explore other architectures, and ultimately led us to an entirely new design shown in the photographs of Fig. 1, and reported previously by Lawson *et al.* (2000) and Swain *et al.* (2002). The principle of operation is simple: an upper carriage carrying the optics sits on four wheels that roll to translate the delay line. There are no axles in this system; the wheels are constrained only by metal straps and a magnetic preload. The carriage has been tuned for a run-out of 25 μm over its full travel—a factor of 10 better than our requirement. Figure 2 shows plots of performance tests at room temperature, showing misalignments with an amplitude of 75 mum. Lab tests have shown that the alignment is maintained well within tolerances over 1000 cycles (16 hrs of cycling).

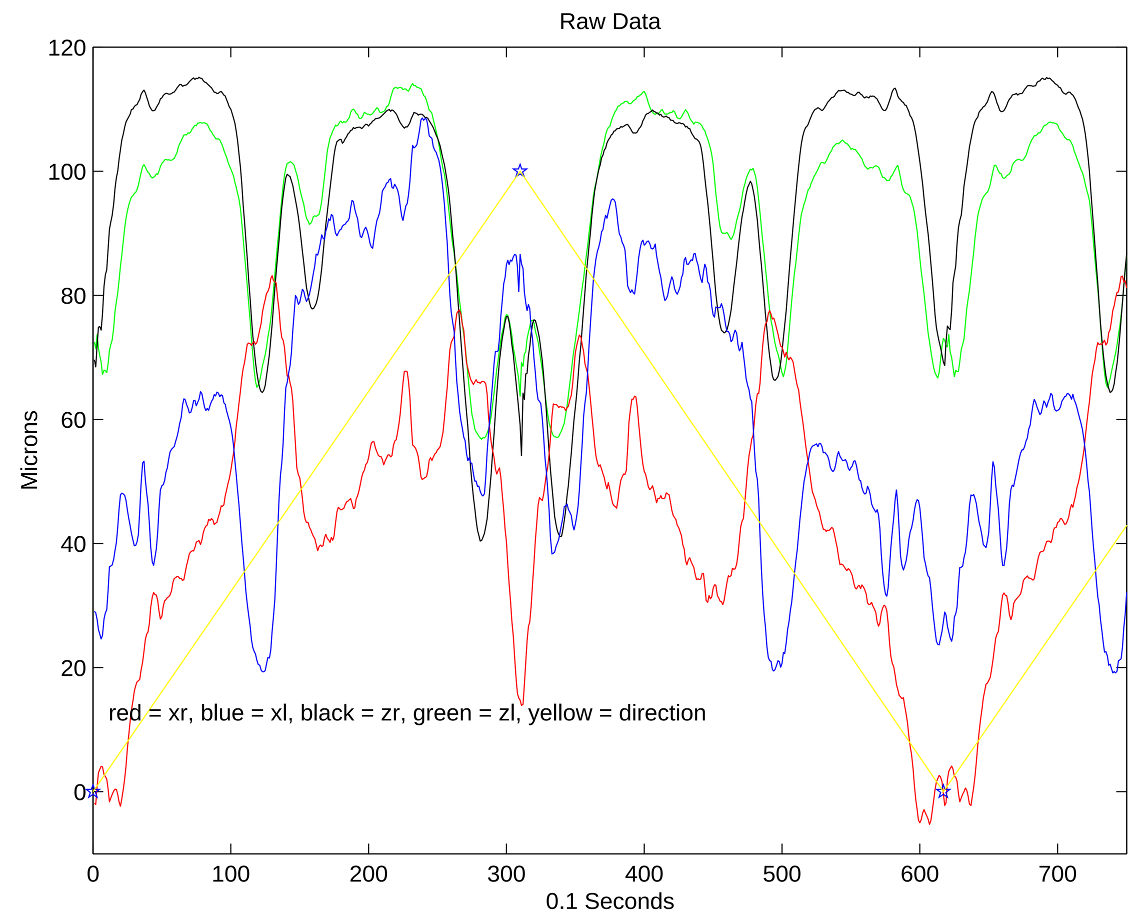

Figure 2: Performance curves for forward and backwards scans of the delay line. The amplitude of the motions are approximately 75 microns, with a prominent linear component in most axes due to misalignment of the straps.

3 Novel Mechanical Amplifier

The ability to measure fringe phase is key to many aspects of astronomical interferometry, and piezo transducers are ideal modulators for most methods of phase measurement, but primarily at visible wavelengths where the stroke lengths are relatively short. At infrared wavelengths and operating at cryogenic temperatures piezos are ill-suited as modulators, because their throw is reduced by as much as a factor of two, and even a wavelength or two of modulation is beyond their capability. The largest commercially available piezo stacks are about 5 inches in length and have a throw of about 180 microns at room temperature and only about 90 microns at 4 Kelvin.

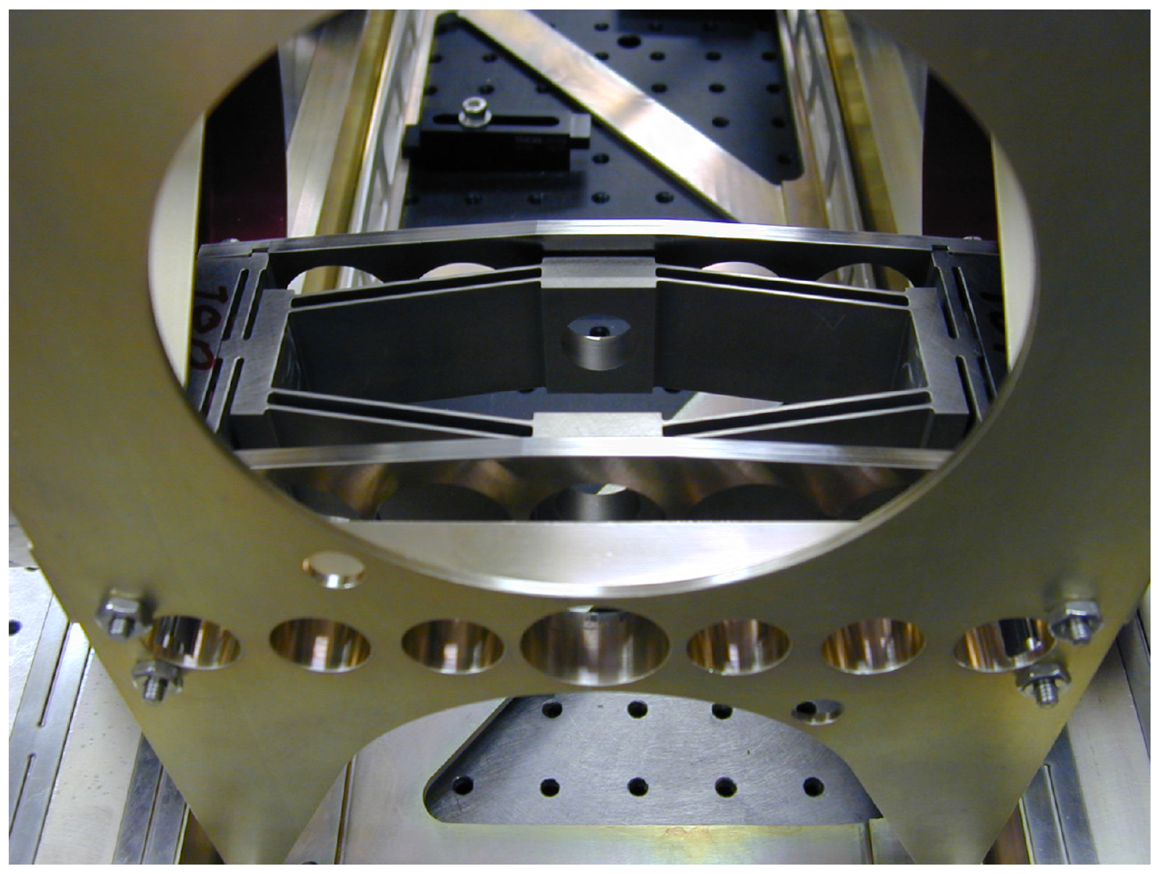

Figure 3: View of the front of the delay line looking into the mechanical amplifier for the piezo stack. When installed, the stack sits inside the parallelogram and mirrors, shown in Fig. 4, are located fore and aft.

To compensate for the loss of travel at cryogenic temperatures, the PZT is mounted in a mechanical amplifier, shown in Figs. 3 and 4, that supports one of the mirrors of the interferometer. The device was designed based on an original concept from Rob Calvet at JPL dating from 1993. The mechanical amplifier resembles an elongated parallelogram with pairs of parallel flexures along each side. The piezo transducer is compressed along the axis of the long diagonal of the parallelogram by support flexures at each end. The expansion of the piezo along the long diagonal causes the ends of the short diagonal to move towards each with a motion amplified by a factor of 3 or 4. The parallel flexures are used to eliminate unwanted twisting and vibration modes so the small mirror will not tilt when translated by the amplifier. The support flexures that hold the piezo allow a symmetrical expansion of the piezo within the amplifier. The design is completely symmetric and balanced such that inertial forces are nulled. This provides mechanical stability that allows rapid (100 Hz) sampling without inducing vibrations. Optical interferometers normally obtain the mechanical stability and momentum compensation by using an additional piezo stack mounted back-to-back with the first piezo so that the second one has motions that are equal but opposite in direction. By mounting the stack symmetrically with the support flexures the stack expands equally about its center, does not induce vibrations, is more compact, and does not require momentum compensation. The device is made of titanium and was machined using a Wire EDM process so as to be as strong and lightweight as possible.

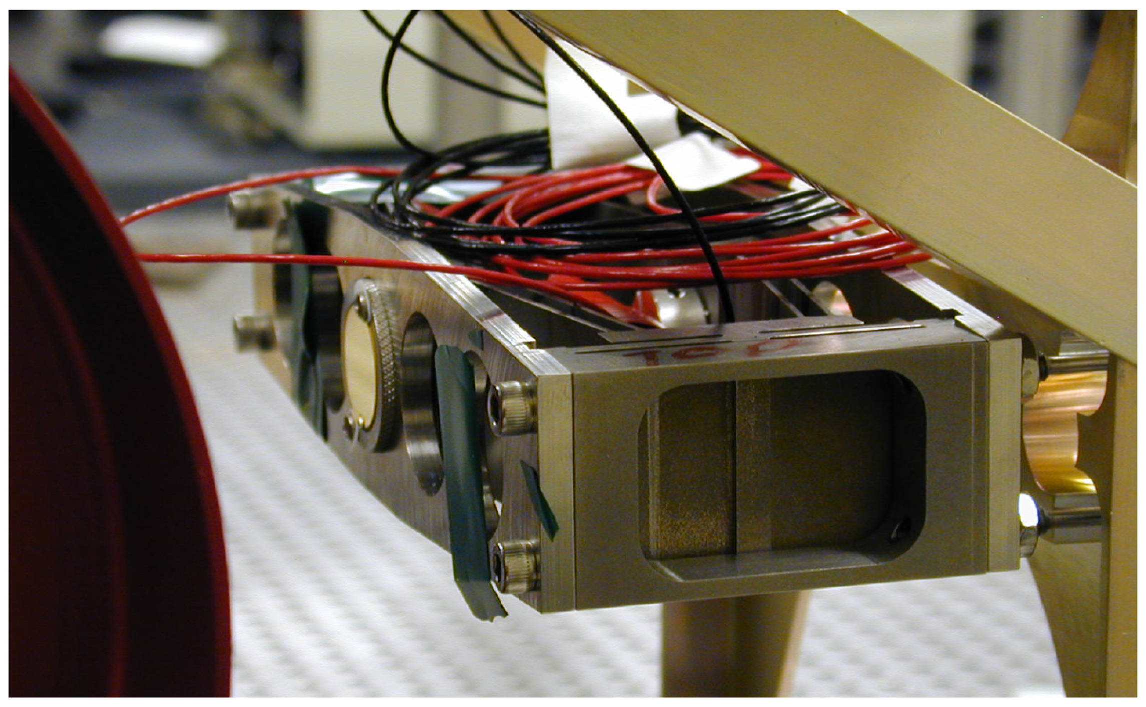

Figure 4: Side view of the mechanical amplifier with the cat's eye secondary mirror now installed.

4 Preliminary Cryogenic Testing

In August 2001 we conducted preliminary tests of the delay line at liquid nitrogen temperatures with the aid of a 150 quart Coleman Marine Cooler. The temperature of the base of the delay line was held at 77 K, which by conduction and after two hours of cooling brought the top of the delay line to 120 K. The delay line was cycled back and forth by a stepper motor for about two hours, operated well, and moved smoothly throughout the testing. Encouraged by these results, we are now in the process of designing a custom-made dewar to be used for future tests. The dewar will be designed with space for a beam combiner, now also under development.

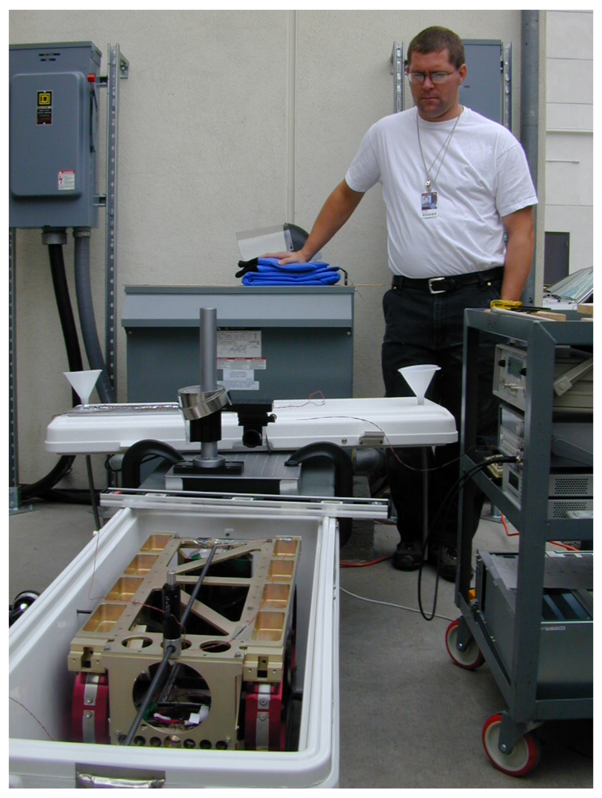

Figure 5: Preparations for cryogenic tests at liquid nitrogen temperatures.

5 Current Status and Future Plans

Initial tests of the delay line have shown the design to be fundamentally sound and operating well within requirements. Further cryogenic tests will be undertaken when the new dewar is completed. Work is now also underway to implement the pathlength servo controls and to test the new mechanical amplifier. Plans are being made to integrate the delay line in a far-infrared interferometer testbed.

References:
G.H. Rieke *et al.* 1999, http://mips.as.arizona.edu/MIPS/fircase3.pdf; P.R. Lawson *et al.* 2000, Bull. Astron. Soc. Am. i**32**, 1426; M.R. Swain *et al.* 2002, Proc. 36th Liège International Astrophys. Colloq.

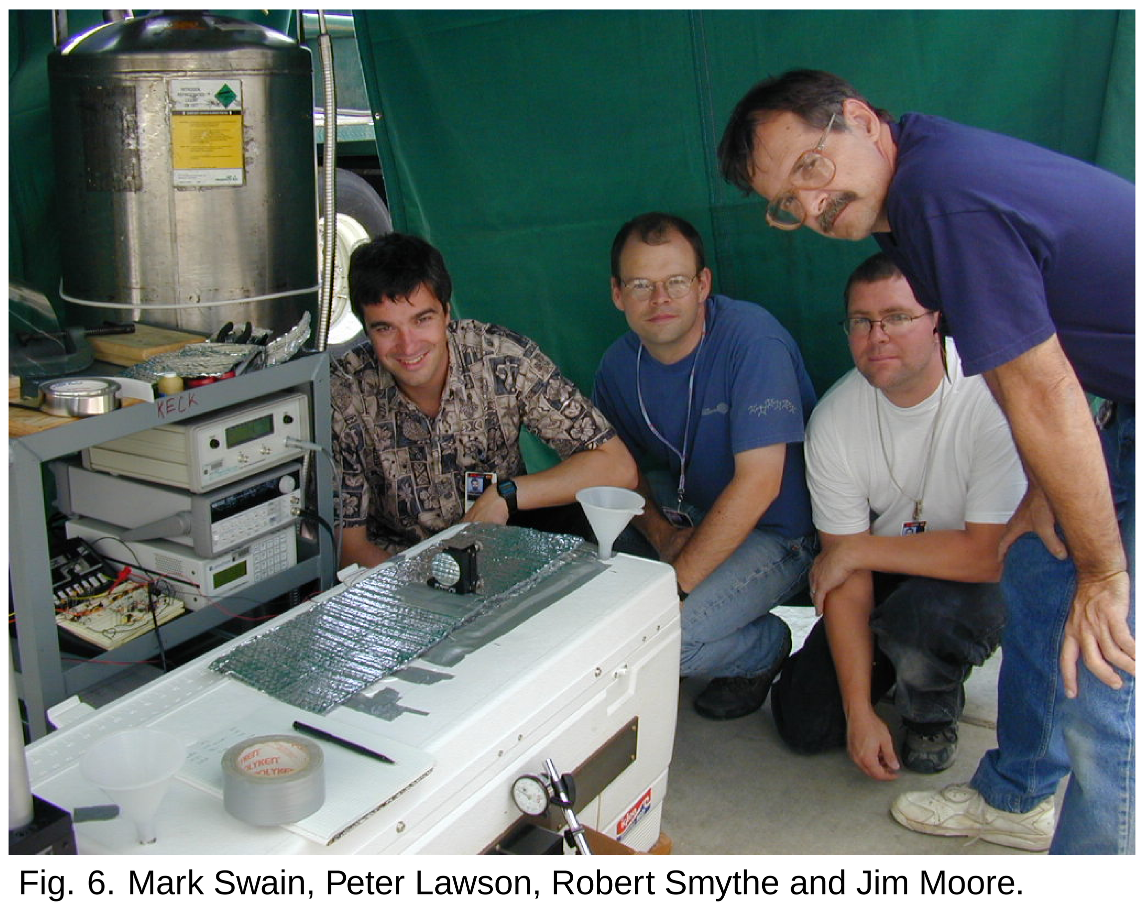

Fig. 6. Mark Swain, Peter Lawson, Robert Smythe and Jim Moore.

Acknowledgements: The authors would like to thank Donald E. Jennings, Rob Calvet, and Chris Walker. This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.